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# THE SEDIMENTATION UNIT AND ITS USE IN FIELD SAMPLING[1]

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## ABSTRACT

Four objectives of quantitative study of sediments are outlined, each of which requires specially collected samples. The corresponding techniques of collection are here called engineering sampling, descriptive sampling, environmental sampling, and correlation sampling, according to the purpose of the samples. The steps in the systematic collection of samples for the first three purposes are outlined. Certain principles underlying efficient correlation sampling are considered.

There are two techniques for environmental sampling depending on the kind of measurements to be made. Criteria are given for determining whether or not composite samples may be used. When composite samples are unsuitable, samples from individual layers are required. In the latter case, the sedimentation-unit concept furnishes a practical field tool for the rational selection of the layer or combination of layers to be sampled as a unit. An example of the use of the sedimentation unit, showing how the boundaries of the individual units are determined, is given in detail. Six general steps for the determination of a sedimentation unit are given. Devices for obtaining the samples are described.

## INTRODUCTION

There is a growing recognition that the problems of field sampling are fully as important as those of laboratory technique. A rational approach to the problem of sampling would be a desirable geological tool. It is proposed to show that such an approach is possible and

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that in many cases the sedimentation unit is a practical unit in the field sampling of sediments.

Laboratory measurements on samples of sediments are generally made for one of four purposes:

1. To determine the suitability of a deposit for economic utilization. The collecting of samples for such a study is here called *engineering sampling.*

2. To permit a detailed petrographic description of a formation or similar unit. The collecting of samples for this purpose is here called *descriptive sampling.* One or more samples may be needed. A series of systematically collected samples enables the variability or homogeneity of a stratigraphic unit to be stated quantitatively.

3. To establish a relation between measurements made on each member of a series of samples and changes in the environment of deposition. A textural variation series[2] of beach sands is an example in which changes in mechanical composition are correlated with net linear distance of travel. Likewise, for areal studies of variation sampling grids are employed to elucidate the environmental "pattern."[3] The collecting of a suite of samples suitable for this purpose is here called *environmental sampling.*

4. To establish similarities or differences between two or more sets of samples from the point of view of geological correlation. The collecting of a suite of samples for this purpose is here called *correlation sampling.*

## ENGINEERING SAMPLING

Mining engineers have devoted much study to the problems of engineering sampling. Their points of view and techniques have been adopted with little modification by geologists. The modifications generally have been made with the intention of retaining the representative-sample concept without using large samples.

Engineering sampling aims to obtain average samples or representative samples. To attain this end a systematic sampling program includes the following steps: The boundaries of the deposit

[2] F. J. Pettijohn and J. D. Ridge, "A Textural Variation Series of Beach Sands from Cedar Point, Ohio," *Jour. Sed. Pet.*, Vol. II (1932), p. 76.

[3] W. C. Krumbein and Esther Aberdeen, "The Sediments of Barataria Bay," *Jour. Sed. Pet.*, Vol. VII (1937), p. 17.

are determined and the area to be sampled is divided into rational subgroups. Each subgroup is divided into arbitrary areas or unit volumes, usually according to a grid pattern, to eliminate personal bias in the sample selection. Some kind of channel sample is taken at each location. Two or more of these may be combined to form a single laboratory sample where the variability is small or where the sampling cost is notably less than the analytical cost. Each channel sample is usually a composite of many layers. The thickness of material included in a single channel sample is determined mainly by economic considerations of the actual exploitation. Only those layers are excluded which could profitably be kept separate in the commercial exploitation of the deposit.

### DESCRIPTIVE SAMPLING

Descriptive sampling ordinarily involves the selection of a few typical samples from spot locations. Thus for a petrographic description of a member of a formation one sample may be selected to represent each facies Samples of conventional hand-specimen size are adequate except for coarse sediments.

However, if a quantitative measure of the homogeneity of a formation is desired, a sampling plan which reduces the personal element in the sampling is needed. A procedure analogous to that used in engineering sampling may be followed:

1. Define the lithologic units of the formation in terms of the agencies and time of deposition. If this cannot be done in the field, then subdivide the formation into relatively large or persistent lithologic units.

2. Fix the geographic limits of the investigation and apply a grid system, preferably three-dimensional, such that the number of samples is consistent with the precision required.

3. Take spot samples from each location. The sample size should be just large enough to represent adequately the rarest or coarsest component under consideration. Each major lithologic unit should be sampled separately.

4. Exclude only those samples which owe their irregularity to the work of an agency not affecting the remaining samples and not included in the investigation. Thus if a sample location determined by

the grid pattern lies in a fault zone, no sample should be taken from that location.

To shorten the laboratory work groups of four or eight adjacent samples may be combined into composite samples. The observed variability of the series of composite samples will be considerably less than the variability computed from determinations on the much larger number of component samples; a mathematical correction[4] can be applied when it is desired to compute a quantitative index of variability.

## ENVIRONMENTAL SAMPLING

The development of efficient procedure for environmental sampling requires recognition of two classes of measurements made on sediments. The first class consists of such measurements as quantitative chemical and mineralogical composition, average diameter, and average sphericity.

Any measurement of this class is an arithmetic mean value of some property of all the particles in the sample, or is a ratio indicating frequency of occurrence. For these measurements the value obtained by analyzing a composite sample is the same as the value obtained by averaging separate analyses of the components. When the component samples represent unequal amounts of the composite sample, weighted averages are used.

The other class of measurements is characterized by the failure of a measurement on a composite sample to agree with the average of measurements made on the component samples. Such failure occurs when the measurement is dependent on the orientation of the individual particles. Porosity and permeability measurements in situ are examples in which the original orientations are lost in the composite sample. Measurements of dispersion of particle sizes such as quartile deviations[5] and the standard phi deviation[6] may also be misleading when made on composite samples. Thus if well-sorted

[4] W. C. Krumbein, "The Probable Error of Sampling Sediments for Mechanical Analysis," *Amer. Jour. Sci.*, Vol. XXVII (1934), pp. 204–14.

[5] W. C. Krumbein, "The Use of Quartile Measures in Describing and Comparing Sediments," *ibid.*, Vol. XXXII (1936), pp. 98–111.

[6] W. C. Krumbein, "Application of Logarithmic Moments to Size Frequency Distributions of Sediments," *Jour. Sed. Pet.*, Vol. VI (1936), p. 40.

beach sand is mixed with well-sorted gravel, the apparent sorting of the composite sample will be poor. This principle can be extended to other measurements in which the distribution of sizes and shapes is a factor, as in measurements of minimum porosity, bulk density, and angle of repose.

The data in Table 1 illustrate these two classes of measurements. Six samples were taken from a desert dune about ten miles southwest of Baker, California, at the southwestern edge of ephemeral

TABLE 1*

STATISTICS OF THE MECHANICAL ANALYSES OF THE CRONISE LAKE DUNE

| Sample No. | Mean Diameter $M_\phi$ | Standard Deviation $\sigma_\phi$ | Median Diameter $Me_\phi$ | Quartile Deviation $QD_\phi$ | Quartiles | |
|---|---|---|---|---|---|---|
| | | | | | $Q_1$ | $Q_3$ |
| 1 | 2.15 | .384 | 2.11 | 0.22 | 2.36 | 1.92 |
| 2 | 2.47 | .315 | 2.47 | .17+ | 2.65 | 2.30 |
| 3 | 2.55 | .294 | 2.57 | .15+ | 2.72 | 2.41 |
| 4 | 2.60 | .377 | 2.60 | .20 | 2.80 | 2.40 |
| 5 | 2.70 | .374 | 2.69 | .20 | 2.90 | 2.50 |
| 6 | 2.76 | .350 | 2.77 | 0.21 | 2.98 | 2.56 |
| Average | 2.54− | .349 | 2.53+ | 0.19 | 2.73+ | 2.35 |
| Composite sample | 2.54 | .402 | 2.54 | 0.22+ | 2.77 | 2.32 |

* The phi scale of particle-size measurement is used, defined by $\phi = -\log_2(\xi)$, where $\xi$ is the diameter of the particle in millimeters. It is especially useful when comparing sediments whose average diameter undergoes a progressive shift from sample to sample. The parameters expressed in phi units are readily adapted to mathematical analysis. Phi measures of dispersion are directly comparable because a given numerical difference signifies the same relative change in particle diameter regardless of the average diameter of the particles.

Cronise Lake. All the samples were taken from the top half-inch of one homogeneous layer. Sample 1 is from the base and Sample 6 is from the crest. One purpose of these samples was the determination of the average sorting under the conditions of deposition prevailing at the time of collection.

The parameters or statistics given in Table 1 summarize most of the information contained in the six sieve analyses. Beneath the data for the six analyses the average value for each statistic is given. The bottom line of the table gives the corresponding parameters of the average sieve analysis. This average analysis was obtained by averaging the percentages on each sieve for the six samples. Note that the two values of $M_\phi$ are the same; for the other statistics, except the median, the average values are different from the values of corresponding statistics of the average sample. In general, the values of the median will be different. In the present example the mean and the median nearly coincide and thus behave similarly.

## ENVIRONMENTAL SAMPLING WHEN COMPOSITE SAMPLES ARE SUITABLE

A modified engineering-sampling program is satisfactory for those environmental-sampling studies for which composite samples are suitable. The area or linear zone to be sampled requires critical definition in terms of the geological agents producing the sediment. Thus in a beach investigation devoted solely to water-deposited sand, the interbedded wind-deposited sand should be removed from the channel samples. The sampling localities are determined by a suitable grid-location system. The depth of the channel samples at each locality is determined by geological conditions such as the thickness of water-laid material deposited since a major storm or during a definite part of a tidal cycle. Samples should not be taken to a uniform depth over the entire area unless it can be shown that the deposit is uniform in thickness. Where there is considerable local variation, such as that introduced by beach cusps, composite samples of several channel samples will smooth these local irregularities and save much laboratory work. The locations of the component channel samples are best determined by a grid pattern adjusted to the scale of the local irregularities. Thus, in sampling cuspate beaches, six channel samples taken from comparable points of the arc between two beach cusps may be combined at each sampling locality. Arbitrary spacing grids are unsatisfactory because they do not take into account the differences in scale of the disturbing factors at the various sampling localities.

## THE SEDIMENTATION UNIT

A sample taken from an apparently homogeneous layer of a sediment is generally composed of a number of laminae. These laminae differ somewhat in average particle diameter so that measures of dispersion for a group of laminae will be greater than the average of the same measures for the individual laminae. To conclude that it is impractical to sample individual laminae, or to agree upon an arbitrary sample volume, is not sufficient. A rational unit for sampling is needed. The writer proposes the sedimentation unit.

*The sedimentation unit at any sampling point is that thickness of sediment which was deposited under essentially constant physical conditions.* Chance deviations of all sedimentary characteristics about a mean value may be present; these deviations, however, should themselves constitute a unimodal distribution. The words "essentially constant" do not preclude the existence of a trend[7] in conditions. This trend may be a simple linear type or a cyclical change in conditions.

The sedimentation-unit concept has proved a valuable field tool in the sampling of various types of beaches, certain types of desert dunes, desert-stream beds, sand and gravel deposited by distributaries on alluvial fans, desert-sand accumulations around bushes, gravel terraces in a canyon, and sediments formed in a canyon by temporary ponding of the water.

The sedimentation unit is more easily visualized in the field in terms of assignable and nonassignable causes of variation and their effect on the laminae of the sediment.

A lamina is the smallest recognizable unit layer of particles of a sediment. The thickness of a lamina may vary from microscopic size for clays to many inches for coarse-gravel deposits.

Nonassignable causes of variation in the characteristics of a sediment are those causes which determine the distinguishing characteristics of individual laminae; the effects of these causes are lost when measurements are made on groups of laminae. Nonassignable causes are recognized by relatively small and rapid fluctuations in their magnitude and the unpredictability of their behavior for even short-time intervals.

Assignable causes of variation in the characteristics of a sediment are those causes which affect adjacent laminae to the same extent or to a uniformly changing extent. Assignable causes of variation are recognized by the predictability of their behavior for considerable

[7] F. C. Mills defines "trend" thus, "The concept of a trend is of a regular smooth underlying movement from which there are deviations, but which marks the long-time tendency of the series" (*Statistical Methods* [Henry Holt & Co., 1924], p. 304).

time intervals, by their relatively long cycles of variation (lasting from many minutes to years, in contrast with cycles of variation lasting seconds or a few minutes as in the case of the nonassignable causes), by the property that a change in the magnitude of the cause produces effects in the composition of the sediment which can be detected by making measurements on adjacent groups of laminae.

### EXAMPLES OF NONASSIGNABLE AND ASSIGNABLE CAUSES OF VARIATION AT THE CRONISE LAKE DUNE

The Cronise Lake dune mentioned previously is held in place by rock hills on the south and west and a highway fill on the north. The dune is situated at the edge of the playa near the mouth of a desert stream and extends to the top of the west rock hill. Sand is swept over the top of the hill during even moderate winds. The average grain size decreases toward the top. The individual laminae are rather indistinct but are grouped together into fairly distinct bands. At the time of the writer's visit the dune was covered with small, remarkably uniform ripple marks.

The field conditions indicate that the growth of the dune (and, consequently, the sedimentation units) is related mainly to weather conditions, principally the magnitude and direction of the wind velocity. For short periods of time in fair weather such growth factors as sand supply, moisture conditions, availability of sand, and size and shape of the dune remain virtually unchanged. The wind variations are of two kinds: the erratic local fluctuations in velocity not specifically assignable to definite causes and those larger variations assignable to definite causes. The former constitute nonassignable causes of variation and the latter assignable causes of variation in the characteristics of the dune. The concept of nonassignable causes may be explained by considering the mode of formation of a single lamina of a ripple-marked dune.

A favorable gust of wind will add a thin layer of sand to the dune. This layer will not be added as a continuous sheet one or more sand grains thick, because the sand is added to a ripple-marked surface. The ripple marks vary in mechanical composition from trough to crest. The minute eddies between each pair of ripple marks cause the newly added sand to be sorted and deposited in bands whose particle size conforms to the difference already existing in different parts of each ripple mark. The ripple marks continually migrate and change their dimensions in response to many minor changes in magnitude and direction of the wind. During rearrangement of the ripple marks, previously deposited laminae will be shifted and mixed with other laminae. A new gust of wind will bring another load of sand. If conditions remain fairly constant, the continued addition of sand will build up the ripple marks by accretion. Layers of sand grains which formerly moved only during rapid changes in the ripple marks will now remain unmoved. The result will be a complex system of laminae, many of which are traceable for a few inches only.

Each lamina owes its distinctive characters to the many slight changes in wind magnitude and direction. These changes are unpredictable. They can be recorded, but even with such a detailed record it is not possible to assign a particular set of fluctuations to a single lamina. Each lamina is the result of a chance cause system which is not constant from one lamina to the next. If the average wind velocity and average direction of the wind remain constant, layers of thirty or more laminae will possess practically identical statistical properties. The effects of the nonassignable causes are eliminated when a number of adjacent laminae are considered as a unit, because the *chance cause system which gave rise to these layers is essentially constant.*

Two assignable causes of variation in wind velocity are movement of storm centers across the continent and diurnal temperature fluctuations which give rise to diurnal winds. In striking contrast to the fluctuations just considered, the approximate magnitude and direction of changes in wind velocity due to these causes are predictable for hours or days ahead from a weather map and a knowledge of meteorology and local conditions. Also it is possible to predict the effects of these changes on mechanical composition and bedding. These predictions are possible despite the presence of nonassignable causes of variation, because the resultant effect of the latter is essentially constant whenever layers of a considerable number of laminae are considered.

Assignable causes of variation usually undergo cyclical changes in magnitude or importance; the effects of these variations are recorded in the sediment as gradual changes in composition within otherwise homogeneous layers. These cycles of variation may last months as in the case of changes in sand supply, or days as in the case of cyclonic winds blowing out from a high-pressure area, or hours as in the case of diurnal winds caused by diurnal temperature changes. For studies lasting only a few days or hours, the slower cyclical changes may be considered constant.

As long as the assignable causes of variation remain essentially constant or change slowly, the sediment deposited continuously during the shortest cycle of variation of these causes constitutes a sedimentation unit. However, if at some stage during the cycle of variation physical conditions undergo a definite change, such as from laminar to turbulent flow in a lake, this change marks a sedimentation-unit boundary. Also if sedimentation ceases locally or is replaced by erosion, the change records a sedimentation-unit boundary.

A series of samples taken from the same sedimentation unit at different sampling points enables regional changes in environment to be correlated with changes in sediment. A series of samples taken from successive layers of laminae within the same sedimentation unit and at a given sampling point enables changes in the cycles of variation of the assignable causes to be correlated with changes in the sediment. Both of these constitute environmental sampling for which the sedimentation-unit concept is intended.

## LOGICAL STEPS FOR THE FIELD DETERMINATION OF SEDIMENTATION UNITS

1. *Define the material to be sampled in terms of the agency or agencies of transportation and the causes of deposition.*—Note that if two agencies of deposition act alternately and portions of the deposits formed by each are left unchanged, the alternate layers cannot be one sedimentation unit.

2. *List the environmental factors which determine the statistical properties of a single lamina and of layers of laminae.*—At Cronise Lake examples of the environmental factors are the composition of the sand brought to the playa, the availability and amount of sand supply, the moisture content of the sand, and the magnitude and direction of wind velocity. Examples of the statistical properties are average particle diameter, dispersion of particles about their average diameter, mineralogical composition, and porosity.

3. *Determine which of these factors can be segregated into assignable causes of variation.*—Of the factors influencing particle diameter, the

composition and availability of the source material and the moisture conditions constitute definitely assignable causes of variation. The effects of changes in each of these factors can be predicted. These factors undergo relatively slow variations and for many studies may be considered constant. Wind-velocity variations, as previously shown, constitute a group with both assignable and nonassignable causes of variation. It is necessary to select individually the assignable causes of variation from this group.

4. *Determine whether the remaining factors are nonassignable causes of variation.*—In this way, unsuspected assignable causes may be disclosed. Usually there are factors which cannot be classed definitely as assignable or nonassignable causes. Summer thunderstorms are an example; their occurrence at a specific locality may seem definitely fortuitous. However, their effects on the growth of a dune are predictable; accordingly, they are assignable causes. Local whirlwinds originating on the playa may rarely come close enough to the dune to cause a violent abnormal wind of short duration The occurrence of this event could scarcely be told from the sediment except immediately thereafter. Such an event is thus considered a nonassignable cause of variation.

5. *Trace the influence of each assignable cause on the physical properties of the laminae by considering what happens when the assignable cause undergoes its expected range or cycle of variation.*—This is done by ordinary inductive reasoning guided by local field conditions. The purpose is to seek those conditions which introduce truncated bedding or rapid changes in the laminae; these mark the boundaries of sedimentation units. As long as the only change in successive layers of laminae is a gradual one, the laminae are part of the same sedimentation unit.

Sedimentation-unit boundaries are determined by relatively sudden changes in an assignable cause or by the entrance or exit of another assignable cause. It needs to be established that the change in environment is capable of producing a recognizable change in the laminae. The magnitude of the effect must be great enough not to be marked by the effect of slight fluctuations in the nonassignable causes from one layer of laminae to the next.[8]

[8] The kind of reasoning involved is illustrated by the following oversimplified analysis of the effects of a high-pressure area in the Nevada-Utah region. Southwester-

6. *As a check on the inductive reasoning, re-examine the bedding planes and stratification for discontinuities and rapid changes not indicated by the inductive analysis.*—If these cannot reasonably be attributed to the nonassignable causes, look for some distinguishing characteristic which may afford a clue to an unsuspected assignable cause.

## FIELD TECHNIQUE FOR ENVIRONMENTAL SAMPLING

Environmental pattern studies are made preferably where sedimentation is actively taking place so that the assignable causes of variation can be determined with assurance. When some member of a geological formation long since deposited is chosen for study, the environment of deposition must be inferred from the physical and paleontological evidence and by detailed comparison with localities where the same sediment is now being deposited. The postulation of causes of variation and the detection of assignable causes are less certain since the reasoning rests on premises which are inferential and consequently subject to greater error than premises based on observation. This disadvantage is often offset by greater accessibili-

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ly regional winds of increasing intensity will blow out from the high-pressure area during its formation. At the Cronise Lake dune these winds will be deflected westward by the hill on the south. Since increasing wind velocity is favorable to dune growth, a layer of sand will be added to the dune. The average particle size will become increasingly coarser because (1) the material brought to the dune is continually getting coarser and (2) because the transporting power of the wind up the dune slopes and over the top of the hill is increasing.

Continued high winds may remove most of the loose sand on the playa. Sand will continue to blow over the top of the hill, resulting in a net loss of material from the upper part of the dune. On the lower slopes of the dune this condition may be marked by deposition of a layer of coarse sand. The start of erosion marks the upper time boundary of the basal sedimentation unit. During the period of decreasing intensity, little change will occur unless the wind direction shifts enough to obtain a new sand supply. A new sand supply will cause coarse grains to be buried beneath finer sand. Renewal of active deposition marks the base of a third sedimentation unit. Where the layer of coarse grains is missing, truncated bedding will mark the base.

Any complete environmental study will consider the areas of nondeposition and erosion. A complete quantitative environmental study of this dune during such a weather cycle as here postulated requires sets of samples from each of three sedimentation units. From the aerodynamic point of view, each set is best collected as soon as deposition has ceased. From the geological point of view, samples collected after the storm has ceased are preferable because they will yield data comparable to those which may be obtained in the geological record.

ty. Thus a recently uplifted portion of sea bottom which still has the shoreline features well preserved may be preferable for some environmental studies because of easy access.

The choice of a locality for an environmental study of a sediment in process of deposition is best made after a reconnaissance examination has eliminated those localities with poorly developed physiographic forms and those areas of deposition complicated by atypical sources of material or by many local sources of material.

An efficient inductive analysis to determine the sedimentation units should be preceded by a careful field examination of the stratification and bedding and an inquiry into climatic and weather conditions which may constitute assignable causes of variation. With these data at hand, little time will be lost investigating the effects of conditions which are known not to have existed during the deposition of the layers involved in the study.

After the sedimentation units have been determined, one or more are chosen for sampling. Only samples coming from the same sedimentation unit are comparable. Thus it is important to establish the continuity of each unit being sampled, since erosion may have completely removed one or more units in places. The correct picture of the environmental pattern will take into account areas of non-deposition or erosion as well as areas of deposition. A sedimentation unit in the process of formation is especially well adapted for study because its continuity is certain. When the area involved in the study is small, shallow trenches are useful to establish continuity. For large areas where samples are taken hundreds of feet or several miles apart, the continuity can often be established by shallow core samples by ordinary geological methods if the units are quite thick. If the environment has remained fairly constant during the deposition of a considerable thickness of material, samples may be taken from comparable portions of the unit. Ordinarily a channel sample extending the full thickness of the sedimentation unit and perpendicular to the base is preferable. If the purpose of the study is to evaluate the effect of a trend in an assignable cause, samples are taken from consecutive layers of laminae within the sedimentation unit; as shown previously, layers of laminae eliminate effects of non-assignable causes.

To obtain the samples the author has found the following equipment satisfactory: a $1\frac{1}{2}$- and a 3-inch diameter cylindrical, galvanized iron tube closed at one end except for a small opening, a 2-ounce round tin box, a 6-ounce round tin box, a rectangular tube 4 inches by 1 inch for sampling layers in a vertical bank, and a 2-inch by $1\frac{1}{2}$-inch scoop shaped like a dustpan.

## CORRELATION SAMPLING

Sampling for correlation by paleontological methods is beyond the scope of this paper. Studies in progress suggest that an empirical adaptation of the sedimentation-unit concept may improve correlation by lithologic methods. Samples from sedimentation units, though desirable, ordinarily cannot be selected, because the determination of sedimentation-unit boundaries presupposes a degree of knowledge which does not exist when correlation of strata is sought.

## SUMMARY

Four kinds of sampling classified according to purpose have been described: engineering sampling, descriptive sampling, environmental sampling, and correlation sampling. The essential features of a systematic sampling program for a sedimentary deposit have been considered for the first three kinds of sampling.

For some environmental studies composite samples are desirable; more often samples from individual layers are preferable. The concept of the sedimentation unit enables the field worker to decide rationally what laminae or layers should be included in the sample. The determination of the sedimentation units requires recognition of two types of causes of variation in sediments: those which determine the distinguishing characteristics of individual laminae and those which determine the statistical properties of layers of laminae. Six logical steps for determination of sedimentation units were presented, followed by suggestions on field technique.

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